

## Response Features Determining Spike Times

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### ABSTRACT

Interpreting messages encoded in single neuronal responses requires knowing which features of the responses carry information. That the number of spikes is an important part of the code has long been obvious. In recent years, it has been shown that modulation of the firing rate with about 25 ms precision carries information that is not available from the total number of spikes across the whole response. It has been proposed that patterns of exactly timed (1 ms precision) spikes, such as repeating triplets or quadruplets, might carry information that is not available from knowing about spike count and rate modulation. A model using the spike count distribution, the low-pass filtered PSTH (bandwidth below 30 Hz), and, to a small degree, the interspike interval distribution predicts the numbers and types of exactly-timed triplets and quadruplets that are indistinguishable from those found in the data. From this it can be concluded that the coarse (<30 Hz) sequential correlation structure over time gives rise to the exactly timed patterns present in the recorded spike trains. Because the coarse temporal structure predicts the fine temporal structure, the information carried by the fine temporal structure must be completely redundant with that carried by the coarse structure. Thus, the existence of precisely timed spike patterns carrying stimulus-related information does not imply control of spike timing at precise time scales.

### INTRODUCTION

Interpreting the information encoded in single neuronal responses requires knowing which response features carry information. Despite a great deal of study, which response features are important is still not completely certain. One approach is to identify the smallest number of parameters that are needed to represent all aspects of neuronal responses encoding information. In formal language, we would like to find the minimum description length for representing neuronal responses. In one sense, to describe a neuronal response, we must specify the arrival time of each spike. We are interested less in the spike train itself, however, than in its role in transmitting information. Therefore, only those aspects of the response that carry unique information need be included.

We have used two approaches. First, we measured the information carried by different response representations with the goal of identifying those carrying information. Second, we sought to develop a statistical model that uses only a few experimental measurements to produce simulated spike trains that are indistinguishable from those recorded during our experiments. Below, we first review the parameters that are known to describe spike trains. We then use these parameters to describe a model that produces simulated spike trains that are indistinguishable from the data.

### OVERVIEW OF METHODS

We recorded 32 LGN and 19 V1 single neurons in awake, fixating monkeys. Stimuli were presented, one at a time, for 280 to 350 ms

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